REVIEW ARTICLE

High Tibial Osteotomy: A Systematic Review and Current Concept

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Abstract

High tibia osteotomy is a common procedure in orthopedic surgery. A precise overview on indications, patients selection, pre-operative planning, surgical technique, methods of fixation, and complications have been presented. This paper focused on the points that should be considered to achieve good long-term outcomes.

Keywords: Genu varum, High tibial osteotomy, Open wedge, Upper tibial osteotomy

Introduction

High tibia osteotomy (HTO) is intended to transfer the mechanical axis from medial to slightly lateral to the midline of the knee to decrease the load and subsequently delay osteoarthritis (OA) (1-3). Some studies showed that regenerative process began after realignment (3-5). HTO was considered as an option to treat an isolated medial compartment OA in varus knees, which was reported by Jackson in 1958 (6). This surgery was not popular until Coventry reported good results in 1973 (2). HTO became more popular in young active patients after improvement in surgical technique, fixation devices, and patient selection with fewer complications (7-10).

Indications

There are some evidences that stretch the indications to ankle problems in patients who have pain and instability because of a varus ankle malalignment (11). Other indications in the presence of varus knee are meniscal transplantation after total medial meniscectomy, isolated chondral defect in the medial compartment of a varus knee, secondary degenerative arthritis in a varus knee with medial joint line pain, and ligamentous instability with varus thrust in which correction of the varus deformity unloads the reconstructed ligament while it heals (12-17).

History and Physical Examination

Observation of patient`s gait and stance especially to assess varus thrust and the presence of lateral collateral ligament insufficiency is of importance. Limb length discrepancy, ankle deformity, joint instability including insufficiency of collateral and cruciate ligaments should be considered for concomitant or staged surgery (18, 19).

Essential radiographs for the primary assessment starts with four views including anteroposterior (AP) and lateral views of the knee, axial view of the patellofemoral joint, and weight-bearing alignment view showing both lower extremities from hip to ankle. Stress views are mandatory when physical exam reveals ligamentous laxity (20). The tibia bone varus angle (TBVA) is measured on AP radiograph [Figure 1] and TBVA >5° is a good prognostic factor after osteotomy (8, 21, 22). Patella height is evaluated on the lateral radiograph using Insall-Salvati index (23).

Patient Selection and Prognosis

The highly accepted protocol was developed by ISAKOS (International Society of Arthroscopy, Knee Surgery and Orthopedic Sports Medicine) in 2004 (19). An ideal patient for HTO is a moderately active high-demand (but not jumping or running), young (between 40-60 years old) with isolated medial joint line tenderness, BMI <30, malalignment <15°, metaphyseal varus (i.e. TBVA>5°),

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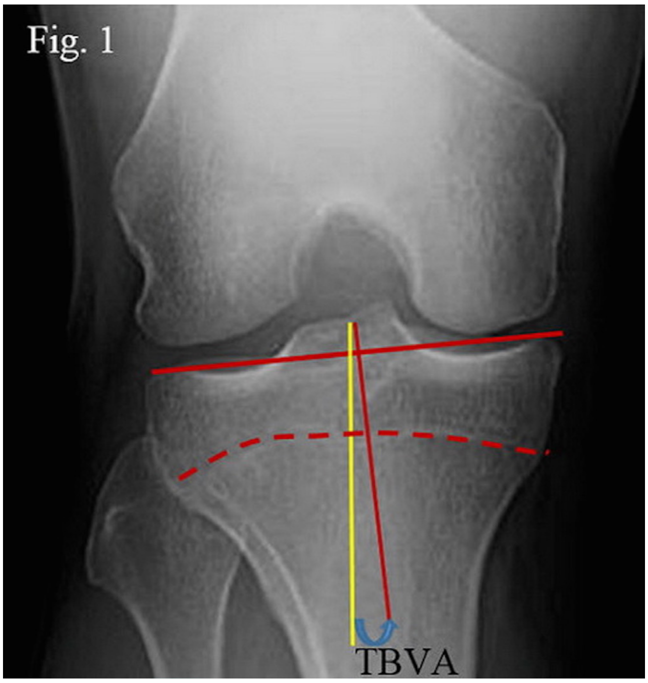

Figure 1. Standard anteroposterior view of the knee. TBVA (arrow) is the angle between the mechanical axis of the tibia (yellow line) and the proximal tibia epiphysial axis (red line).

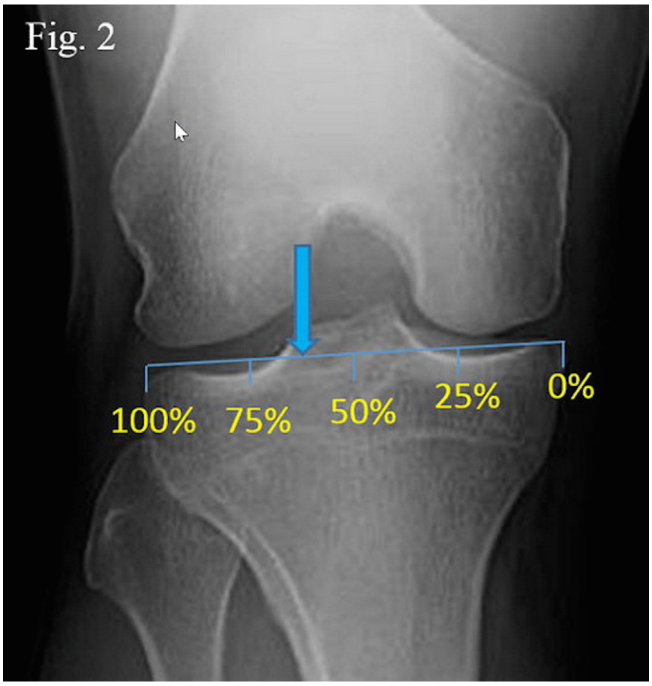

Figure 2. Fujisawa detemined a point (arrow) located at 62% of the tibial plateau width when measured from the medial tibial plateau.

full range of motion (ROM), near-normal lateral and patellofemoral compartments, without ligamentous instability, non-smoker, and with some level of pain tolerance. HTO is contraindicated in patients older than 65, severe OA of the medial compartment (Ahlback grade III or higher), tricompartmental OA, patellofemoral OA, ROM<120° and flexion contracture >5°, diagnosed inflammatory arthritis, large area of exposed bone on tibial and femoral articular surface (> 15x15 mm), and heavy smokers (2, 24-32).

Good prognostic factors are preoperative TBVA>5°, postoperative obliquity of tibiofemoral joint line in a narrow range close to 0°, anatomical valgus alignment of ≥8° at five weeks post operation, age<50 years, excellent preoperative Knee Society score, and Ahlback grade 0 arthritis of medial plateau (33-36). Negative prognostic factors are obesity especially more than 1.3 times of the normal population weight, nicotine users, valgus alignment of ≤5° at five weeks post operation, postoperative flexion<120°, and age>56 years old (34, 36).

Niemeyer et al published a minimum of 36-month follow-up of 69 patients after medial open wedge high tibial osteotomy (MOWHTO). They concluded that the severity of medial plateau cartilage defect did not affect the clinical results of surgery, and partial thickness defect in lateral tibial plateau was well-tolerated (8).

Pre-operative Planning

Mechanical axis (line from the center of the femoral head to the center of the knee), anatomical axis (a line from the piriformis fossa to the center of the knee joint and a line through the long axis of the tibia), and weight bearing axis (line drawn from the center of the femoral head to the center of ankle joint) are measured on the alignment view, where the location, type, and amount of corrective osteotomy is determined. Normally 60% of the body weight force passes through the medial compartment (37). Normal values include a mechanical axis of 1-3° varus, anatomical axis of 5-7° valgus, 6° of valgus between the mechanical and anatomical axes, and the weight bearing line passing through the lateral 30-40 % of the tibial plateau (37-40). Unicompartmental OA usually becomes symptomatic when the alignment is more than 10° off of the normal range (41).

The goal of valgus HTO is to reach a slight valgus axis to prevent recurring of varus. Nearly 8-10° of valgus in the anatomical axis or 3-5° of valgus in the mechanical axis are considered optimal correction after surgery (28, 42-47). Slight varus correction can lead to recurrence of deformity whereas overcorrection can cause lateral compartment OA (28, 42).

In our practice, we use a simple approach to determine the angle of correction that originally goes back to the research of Fujisawa et al and later adapted as a guideline to determine pre and postoperative amount of varus correction (40, 48). The weight bearing line (WBL) should pass from 62% of the tibial plateau width when measured from the edge of the medial tibial plateau [Figure 2]. This point – called Fujisawa point – matches over the mechanical axis with 3-5° valgus and locates slightly lateral to the lateral tibial spine. To determine the amount of required correction, a line is drawn from this point to the center of the femoral head and another to the center of the ankle joint. The angle created by

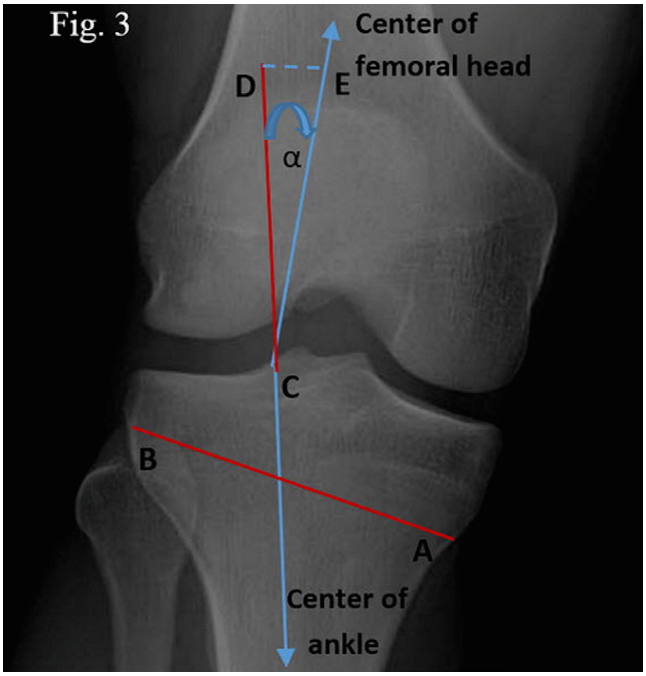

Figure 3. Anteroposterior weight-bearing alignment view is used for pre-operative planning. To determine the weight-bearing line, two separate lines are drawn from the center of the femoral head and the center of ankle toward the Fujisawa point. The angle (α) is made by intersection of these two lines indicating the amount of correction needed. The osteotomy line (red line) is drawn from the medial aspect of proximal metaphyseal plateau (A) to the tip of the fibular head (B). AB is transferred to the rays of the α angle to make the CD line. DE distance is measured in milimeters, which represents the amont of opening required after osteotomy.

these two lines indicates the amount of correction. Then the osteotomy line is drawn at about 4 cm below the medial joint line toward the fibular head. This line is measured in millimeters and should be transfered to the apex of triangle that is now created [Figure 2]. The width of the triangle's base is measured in millimeters, which corresponds to the amount of correction required during a medial open wedge osteotomy (49).

Surgical Technique

It is recommended to start the surgery with knee arthroscopy to debride the lateral compartment and manage the concomitant pathologies (50). Medial opening wedge, lateral closing wedge, and dome osteotomy are comparable techniques in the correction of genovarum.

Lateral closing wedge osteotomy

Lateral closing wedge osteotomy is the historic approach and is more familiar to some surgeons. The advantages are greater potential of correction, no need for bone grafting, and faster healing (27, 34, 42, 43, 51-53). Disadvantages are concomitant fibular osteotomy or release of the proximal tibiofibular joint, risk of peroneal nerve injury (occurs in 3.3-11.9%), the need for two bone cuts, ability of malalignment correction in only one plane (frontal), shortening of the leg, loss of bone stock, and more difficult conversion to arthroplasty with muscle detachment (7, 44, 54-58).

An anterolateral L-shaped incision is made starting 1 cm below the joint line that continues toward the lateral edge of the tibial tubercle and anterior tibial crest. The anterior compartment fascia is cut close to the anterior tibial crest and anterior tibialis muscle is elevated using a periosteal elevator to expose the bone. Osteotomy starts above the tibial tubercle preferably 15 mm below the joint line (59-66). Shorter distance from the joint line may cause ancillary fracture or avascular necrosis of the tibial plateau. Osteotomy is directed medially parallel to the joint line. Medial cortex and periosteum is preserved to act as a hinge while closing the osteotomy. It is highly recommended to remove a wedge 2-3 mm smaller than preoperational planning to avoid overcorrection by overlapping the proximal and distal bone segments (49).

Medial opening wedge osteotomy

Medial open wedge osteotomy has been more popular recently. The advantages are the ability to correct the alignment in two planes (coronal and sagittal), no need for fibular osteotomy, little risk of peroneal nerve injury, no limb shortening, use of a single cut with no need to detach the muscles, no bone loss, easier conversion to arthroplasty, and ability to adjust the amount of correction during surgery. Disadvantages are the need for bone graft, and the risk of delayed union or nonunion (7, 19, 34, 51-54, 66). MCL becomes slightly tight after MOWHTO. Moreover, surgeon should be cautious about increasing in posterior tibial slope (PTS), patella height (PH) and patellofemoral compartment pressure that often occur when too much correction is done (67, 68). McNamara et al suggested a concomitant tibial tuberosity osteotomy if more than 12.5 mm correction is required to avoid adverse effects of patella infra and increased

Table 1. Studies reporting the results of the Spacer plate and Tomofix plate

Study	Published	Implant	Failure rate
Lobenhoffer and Agneskirchner (7)	KSSTA, 2003	Spacer plate	6% in 101 patients
Spahn et al (80)	Arch Orthop Trauma Surg, 2004	Angle stable implant and spacer plate	No failure in angle stable implant, 11.7% failure in spacer plates
Staubli et al (9)	Injury, 2003	TomoFix	2% failure in 92 patients
Lobenhoffer, Agneskirchner and Zoch (88)	Orthopade, 2004	TomoFix	No failure in 262 patients, 2 patients neededrequired bone grafting.

patellofemoral compartment pressure (69).

An incision is made in the midway between posteromedial border of the tibia and medial aspect of the tibial tuberosity. Sartorius fascia is cut and retracted medially to expose the medial collateral ligament (MCL). It is necessary to peel off the MCL from its insertion to unload the medial compartment after osteotomy (70).

Han et al studied on 18 fresh frozen human cadaver knees and found a safe zone to avoid breaking the lateral cortex (71). This safe zone is an area between the tip of the fibular head and the remnant of fibular head epiphysis line [Figure 3]. Two K-wires are placed 4 cm below the medial joint line toward the safe zone of the lateral cortex under fluoroscopy and osteotomy is done below and parallel to the k-wires using an oscillating saw leaving the lateral 10 mm intact. Care must be taken to preserve this hinge in the lateral cortex while the two thirds of the medial and posteromedial cortex is cut. Thin osteotomes are used to gradually open the osteotomy and finally a calibrated osteotome is used to achieve the desired correction.

To keep PTS and PH within the normal range, the authors follow the recommendations of Hernigou et al and Noyes et al (72, 73). A study by Asada et al showed that excess increase in the PTS resulted in loss of correction in the coronal plane and failure of surgery (74).

Increase in the PTS occurs after MOWHTO whereas lateral closing wedge osteotomy decreases the PTS (75, 76). Increase in PTS also increases the anterior tibial translation and the contact pressure in the posterior compartments (77). Navigation system for the assessment of correction during surgery can only help avoid over- or under correction (78, 79).

Methods of fixation

Plate fixation

Spacer plates (i.e. the Puddu plate and Aescula plate) are small, low profile implants that require small incision with less soft tissue damage. However, these plates are less rigid with the possibility of delayed union, nonunion, and failure of fixation leading to increased posterior tibial slope (7, 74, 80, 81), which necessitates longer period of non-weight bearing for at least 6 weeks after surgery (19, 82) [Table 1].

Plate fixators (i.e. The TomoFix plate) are based on the locking compression plate (LCP) concept offering the advantage of a rigid fixation, possibility of early weight bearing after two weeks, and early start of motion while the normal preoperative PTS is maintained (8, 19, 74, 83, 84). Eight locking bolts are the minimum required number of screws for a rigid fixation with four proximal and four distal to the osteotomy site. At first, the proximal bone segment should be fixed and a lag screw is then inserted in the first distal hole below the osteotomy to increase stability by applying compression on the lateral hinge of the osteotomy. Unicortical screws are inserted in the three remaining bolts.

Agneskirchner et al studied the biomechanics of 3 spacer plates with different length, two with locking bolts, and one was the TomoFix fixator (85). The TomoFix plates were superior at single load-to-failure and cyclical load-to-failure tests and had the maximum residual stability after failure of the lateral cortex. Also motion at the osteotomy gap was the least with the TomoFix plate. Other studies have shown that the TomoFix plate was superior over the spacer plates in achieving rigid fixation and allowing early weight bearing (86-88).

Kachooei et al reported good short term outcome for MOWHTO with Orthopedic Dual Sliding Compression Plate (ODSCP) using 2 to 3 non-locking screws on each side (89). The plate is inserted before correcting the alignment to hold the bone fragments in place. This removes the potential risk of unwanted translation or rotation of the bone, which used to be a complication of the traditional procedures. Further, if the angle of the limb alignment needs to be readjusted after surgery, this plate enables this without the need to remove the bone screws because of the double sliding plates. Inserting the bone screws takes place before the correction force is applied with the screws locating beneath the plateau, thereby reducing the chance of extension of the osteotomy into the joint.

Bone healing after HTO

Staubli et al studied the bone healing using radiography after HTO without filling the osteotomy gap. They showed that healing starts from the lateral hinge and gradually progresses toward medial (90). Callus formation and ossification is visible three months after surgery. The new bone fills 75% of the gap 6 months after surgery. Almost 90% of the patients achieve full consolidation on radiography, CT scan, and MRI in one year.

Spacers for MOWHTO

Many surgeons prefer to fill the osteotomy gap with grafts or bone substitute to enhance stability and accelerate the healing. Onodera et al studied on 38 patients undergoing MOWHTO using locking plate fixation and ceramic spacers (91). They found that post operative alignment and clinical outcome were comparable between hydroxyapatite (HAp) and beta-tricalcium phosphate (TCP), but TCP was significantly superior for oseoconductivity and bioabsorbability after 18 months. Gaasbeek et al evaluated the site of osteotomy during plate removal after MOWHTO using TomoFix fixation and TCP filler (92). They observed that TCP was absorbed and the new bone was completely remodeled and incorporated into the native bone.

Autograft

Autogenous iliac bone graft should be considered as a good option in patients who are at risk of nonunion such as smokers and obese patients (93). Results with autograft were much better with lower complications in comparison with allograft and bone substitutes such as the calcium-phosphate ceramic spacer (94).

Postoperative rehabilitation

The protocol mainly depends on the rigidity of the fixation. In terms of fixation with plate fixators patients are allowed to start partial weight bearing (15-20 kg) immediately after surgery depending on the amount of pain and wound healing while full weight bearing is allowed after two weeks. Luites et al mentioned that there was no difference in weight bearing protocol between open and closed wedge HTO when fixed with the TomoFix plates (95). Since spacer plates are less stable, partial weight bearing is allowed at least 6 weeks after surgery.

Survival rate of HTO

Good long term results are closely related to correct patient selection, surgical technique, rigid fixation, and postop protocol. Ten-year survival rates for closed wedge osteotomy were reported from 51% by Naudie et al to 93.2% by Koshino et al (25, 34, 51, 59). The best results by Koshino was related to some post operation factors including no flexion contracture, valgus anatomical angle of 10°, and concomitant patellofemoral decompression procedure if indicated (96). Coventry et al also reported a 10 year delay in total knee arthroplasty in 75% of patients if overcorrection to at least 8° of valgus was achieved (34). Studies on MOWHTO showed a 10-year delay in arthroplasty in 63% of 73 patients (97), and 85% of 203 patients (97, 98). Longer delay in arthroplasty can be achieved if patients are selected based on TBVA (21,22).

Schallberger et al followed 54 patients with isolated medial compartment OA for a median of 16.5 years that were treated by either MOWHTO or lateral closing wedge osteotomy, and found 24% conversion to total knee arthroplasty. Moreover, there was no significant difference in score outcome and survival between open medial and closed lateral high tibia osteotomy (99).

In a randomized controlled trial on 92 patients after 6 years follow up, Duivenvoorden et al did not find any difference between MOWHTO and lateral closing wedge in terms of clinical outcome or radiographic alignment, in patients who did not end up to joint replacement. Authors showed that the MOWHTO was related to higher incidence of complications whereas the lateral closing wedge osteotomy was related to higher number of conversion to total joint replacement (100). Generally the results of high tibia osteotomy are good within the first ten years and deteriorate after 15 years (101, 102).

Complications

MOWHTO became more popular because of more favorable outcomes (103). Complication was reported from 8% to 55% after MOWHTO (81, 104-106). Lateral cortex breakage is considered an important risk factor for failure of fixation, which might result to at least 4° of loss of correction between immediate and final postoperative radiographs (94). Giuseffi et al evaluated 100 consecutive MOWHTO with a follow up of 4 years where they found that allograft combined with plasma rich platelets and/or DBM increased the risk of nonunion (107).

Martin et al classified complications into three groups based on the patient reported outcome and requiring a treatment. Patients in groups 1 (no additional treatment) and 2 (conservative treatment) comprised more than 90% of patients. Only patients in group 3 required additional surgery or long term medical treatment for aseptic nonunion, deep infection, CRPS type 2, and severe hardware failure with loss of correction. Rate of additional surgery was about 3%. Severe adverse events were more common in patients with diabetes, active smoking, displaced lateral hinge fractures, and patients with no compliance (108).

High tibia osteotomy is a viable solution to address lower limb malalignment with concomitant OA, meniscal deficiency, focal chondral defects, and/or ligamentous instability.

A comprehensive history and physical examination, precise patient selection and preoperative planning, using the appropriate fixation technique and rehabilitation protocol could help to achieve good long-term outcome.

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References

1. Maquet P. The treatment of choice in osteoarthritis of the knee. Clin Orthop Relat Res. 1985; 192:108-12.
2. Coventry MB. Osteotomy about the knee for degenerative and rheumatoid arthritis. J Bone Joint Surg Am. 1973; 55(1):23-48.
3. Akamatsu Y, Koshino T, Saito T, Wada J. Changes in osteosclerosis of the osteoarthritic knee after high tibial osteotomy. Clin Orthop Relat Res. 1997; 334:207-14.
4. Takahashi S, Tomihisa K, Saito T. Decrease of osteosclerosis in subchondral bone of medial compartmental osteoarthritic knee seven to nineteen years after high tibial valgus osteotomy. Bull Hosp Jt Dis. 2002; 61(1-2):58-62.
5. Jung WH, Takeuchi R, Chun CW, Lee JS, Ha JH, Kim JH, et al. Second-look arthroscopic assessment of cartilage

regeneration after medial opening-wedge high tibial osteotomy. Arthroscopy. 2014; 30(1):72-9.

6. Jackson JP. Osteotomy for Osteoarthritis of the Knee. J Bone Joint Surg Br. 1958; 40(4):826.
7. Lobenhoffer P, Agneskirchner JD. Improvements in surgical technique of valgus high tibial osteotomy. Knee Surg Sports Traumatol Arthrosc. 2003; 11(3):132-8.
8. Niemeyer P, Schmal H, Hauschild O, von Heyden J, Südkamp NP, Köstler W. Open-wedge osteotomy using an internal plate fixator in patients with medial-compartment gonarthritis and varus malalignment: 3-year results with regard to preoperative arthroscopic and radiographic findings. Arthroscopy. 2010; 26(12):1607-16.
9. Staubli AE, De Simoni C, Babst R, Lobenhoffer P. TomoFix: a new LCP-concept for open wedge osteotomy of the medial proximal tibia--early results in 92 cases. Injury. 2003; 34(Suppl 2):B55-62.
10. Sommer C, Gautier E, Müller M, Helfet DL, Wagner M. First clinical results of the Locking Compression Plate (LCP). Injury. 2003; 34(Suppl 2):B43-54.
11. Elson DW, Paweleck JE, Shields DW, Dawson MJ, Ferrier GM. Stretching the indications: high tibial osteotomy used successfully to treat isolated ankle symptoms. BMJ Case Rep. 2013; 2013:1-4.
12. Van Thiel GS, Frank RM, Gupta A, Ghodadra N, Shewman EF, Wang VM, et al. Biomechanical evaluation of a high tibial osteotomy with a meniscal transplant. J Knee Surg. 2011; 24(1):45-53.
13. Mina C, Garrett WE Jr, Pietrobon R, Glisson R, Higgins L. High tibial osteotomy for unloading osteochondral defects in the medial compartment of the knee. Am J Sports Med. 2008; 36(5):949-55.
14. Morrey BF. Upper tibial osteotomy for secondary osteoarthritis of the knee. J Bone Joint Surg Br. 1989; 71(4):554-9.
15. Li Y, Zhang H, Zhang J, Li X, Song G, Feng H. Clinical outcome of simultaneous high tibial osteotomy and anterior cruciate ligament reconstruction for medial compartment osteoarthritis in young patients with anterior cruciate ligament-deficient knees: a systematic review. Arthroscopy. 2015; 31(3):507-19.
16. Noyes FR, Barber SD, Simon R. High tibial osteotomy and ligament reconstruction in varus angulated, anterior cruciate ligament-deficient knees. A two- to seven-year follow-up study. Am J Sports Med. 1993; 21(1):2-12.
17. Zaffagnini S, Bonanzinga T, Grassi A, Marcheggiani Muccioli GM, Musiani C, Raggi F, et al. Combined ACL reconstruction and closing-wedge HTO for varus angulated ACL-deficient knees. Knee Surg Sports Traumatol Arthrosc. 2013; 21(4):934-41.
18. Preston CF, Fulkerson EW, Meislin R, Di Cesare PE. Osteotomy about the knee: applications, techniques, and results. J Knee Surg. 2005; 18(4):258-72.
19. Brinkman JM, Lobenhoffer P, Agneskirchner JD, Staubli AE, Wymenga AB, van Heerwaarden RJ. Osteotomies around the knee: patient selection, stability of fixation and bone healing in high tibial osteotomies. J Bone Joint Surg Br. 2008; 90(12):1548-57.
20. Murphy SB. Tibial osteotomy for genu varum. Indications, preoperative planning, and technique. Orthop Clin North Am. 1994; 25(3):477-82.
21. Bonnin M, Chambat P.Current status of valgus angle, tibial head closing wedge osteotomy in media gonarthrosis. Orthopade. 2004; 33(2):135-42.
22. Jenny JY, Tavan A, Jenny G, Kehr P. Long-term survival rate of tibial osteotomies for valgus gonarthrosis. Rev Chir Orthop Reparatrice Appar Mot. 1998; 84(4):350-7.
23. Phillips CL, Silver DA, Schranz PJ, Mandalia V. The measurement of patellar height: a review of the methods of imaging. J Bone Joint Surg Br. 2010; 92(8):1045-53.
24. Flecher X, Parratte S, Aubaniac JM, Argenson JN. A 12-28-year followup study of closing wedge high tibial osteotomy. Clin Orthop Relat Res. 2006; 452:91-6.
25. Naudie D, Bourne RB, Rorabeck CH, Bourne TJ. The Install Award. Survivorship of the high tibial valgus osteotomy. A 10- to -22-year followup study. Clin Orthop Relat Res. 1999; 367:18-27.
26. Gstöttner M, Pedross F, Liebensteiner M, Bach C. Long-term outcome after high tibial osteotomy. Arch Orthop Trauma Surg. 2008; 128(1):111-5.
27. Aglietti P, Rinonapoli E, Stringa G, Taviani A. Tibial osteotomy for the varus osteoarthritic knee. Clin Orthop Relat Res. 1983; 176:239-51.
28. Ivarsson I, Myrnerts R, Gillquist J. High tibial osteotomy for medial osteoarthritis of the knee. A 5 to 7 and 11 year follow-up. J Bone Joint Surg Br. 1990; 72(2):238-44.
29. Rudan JF, Simurda MA. High tibial osteotomy. A prospective clinical and roentgenographic review. Clin Orthop Relat Res. 1990; 255:251-6.
30. Insall JN, Joseph DM, Msika C. High tibial osteotomy for varus gonarthrosis. A long-term follow-up study. J Bone Joint Surg Am. 1984; 66(7):1040-8.
31. Stuchin SA, Johanson NA, Lachiewicz PF, Mont MA. Surgical management of inflammatory arthritis of the adult hip and knee. Instr Course Lect. 1999; 48:93-109.
32. Markolf KL, Bargar WL, Shoemaker SC, Amstutz HC. The role of joint load in knee stability. J Bone Joint Surg

Am. 1981; 63(4):570-85.
33. Babis GC, An KN, Chao EY, Rand JA, Sim FH. Double level osteotomy of the knee: a method to retain joint-line obliquity. Clinical results. J Bone Joint Surg Am. 2002; 84-A(8):1380-8.
34. Coventry MB, Ilstrup DM, Wallrichs SL. Proximal tibial osteotomy. A critical long-term study of eighty-seven cases. J Bone Joint Surg Am. 1993; 75(2):196-201.
35. Odenbring S, Tjörnstrand B, Egund N, Hagstedt B, Hovelius L, Lindstrand A, et al. Function after tibial osteotomy for medial gonarthrosis below aged 50 years. Acta Orthop Scand. 1989; 60(5):527-31.
36. Bonasia DE, Dettoni F, Sito G, Blonna D, Marmotti A, Bruzzone M, et al. Medial opening wedge high tibial osteotomy for medial compartment overload/arthritis in the varus knee: prognostic factors. Am J Sports Med. 2014; 42(3):690-8.
37. Hsu RW, Himeno S, Coventry MB, Chao EY. Normal axial alignment of the lower extremity and load-bearing distribution at the knee. Clin Orthop Relat Res. 1990; 255:215-27.
38. Moreland JR, Bassett LW, Hanker GJ. Radiographic analysis of the axial alignment of the lower extremity. J Bone Joint Surg Am. 1987; 69(5):745-9.
39. Tetsworth K, Paley D. Malalignment and degenerative arthropathy. Orthop Clin North Am. 1994; 25(3):367-77.
40. Fujisawa Y, Masuhara K, Shiomi S. The effect of high tibial osteotomy on osteoarthritis of the knee. An arthroscopic study of 54 knee joints. Orthop Clin North Am. 1979; 10(3):585-608.
41. Iorio R, Healy WL. Unicompartmental arthritis of the knee. J Bone Joint Surg Am. 2003; 85-A(7):1351-64.
42. Hernigou P, Medevielle D, Debeyre J, Goutallier D. Proximal tibial osteotomy for osteoarthritis with varus deformity. A ten to thirteen-year follow-up study. J Bone Joint Surg Am. 1987; 69(3):332-54.
43. Coventry MB. Upper tibial osteotomy for osteoarthritis. J Bone Joint Surg Am. 1985; 67(7):1136-40.
44. Engel GM, Lippert FG 3rd. Valgus tibial osteotomy: avoiding the pitfalls. Clin Orthop Relat Res. 1981; 160:137-43.
45. Kettelkamp DB, Chao EY. A method for quantitative analysis of medial and lateral compression forces at the knee during standing. Clin Orthop Relat Res. 1972; 83:202-13.
46. Koshino T, Morii T, Wada J, Saito H, Ozawa N, Noyori K. High tibial osteotomy with fixation by a blade plate for medial compartment osteoarthritis of the knee. Orthop Clin North Am. 1989; 20(2):227-43.
47. Myrnerts R. Optimal correction in high tibial osteotomy for varus deformity. Acta Orthop Scand. 1980; 51(4):689-94.
48. Dugdale TW, Noyes FR, Styer D. Preoperative planning for high tibial osteotomy. The effect of lateral tibiofemoral separation and tibiofemoral length. Clin Orthop Relat Res. 1992; 274:248-64.
49. Rossi R, Bonasia DE, Amendola A. The role of high tibial osteotomy in the varus knee. J Am Acad Orthop Surg. 2011; 19(10):590-9.
50. Müller M, Strecker W. Arthroscopy prior to osteotomy around the knee? Arch Orthop Trauma Surg. 2008; 128(11):1217-21.
51. Aglietti P, Buzzi R, Vena LM, Baldini A, Mondaini A. High tibial valgus osteotomy for medial gonarthrosis: a 10- to 21-year study. J Knee Surg. 2003; 16(1):21-6.
52. Berman AT, Bosacco SJ, Kirshner S, Avolio A Jr. Factors influencing long-term results in high tibial osteotomy. Clin Orthop Relat Res. 1991; 272:192-8.
53. Holden DL, James SL, Larson RL, Slocum DB. Proximal tibial osteotomy in patients who are fifty years old or less. A long-term follow-up study. J Bone Joint Surg Am. 1988; 70(7):977-82.
54. Devgan A, Marya KM, Kundu ZS, Sangwan SS, Siwach RC. Medial opening wedge high tibial osteotomy for osteoarthritis of knee: long-term results in 50 knees. Med J Malaysia. 2003; 58(1):62-8.
55. Patond KR, Lokhande AV. Medial open wedge high tibial osteotomy in medial compartment osteoarthrosis of the knee. Natl Med J India. 1993; 6(3):104-8.
56. Kettelkamp DB, Leach RE, Nasca R. Pitfalls of proximal tibial osteotomy. Clin Orthop Relat Res. 1975; 106:232-41.
57. Kirgis A, Albrecht S. Palsy of the deep peroneal nerve after proximal tibial osteotomy. An anatomical study. J Bone Joint Surg Am. 1992; 74(8):1180-5.
58. Recommendations for the optimal care of the traumatized and/or burned patients. Part IV. The North Carolina Committee on Trauma of the American College of Surgeons. N C Med J. 1980; 41(12):818-23.
59. Billings A, Scott DF, Camargo MP, Hofmann AA. High tibial osteotomy with a calibrated osteotomy guide, rigid internal fixation, and early motion. Long-term follow-up. J Bone Joint Surg Am. 2000; 82(1):70-9.
60. Coventry, M.B., Upper tibial osteotomy. Clin Orthop Relat Res, 1984(182): p. 46-52.
61. Grelsamer RP. Unicompartmental osteoarthrosis of the knee. J Bone Joint Surg Am. 1995; 77(2):278-92.
62. Leutloff D, Tobian F, Perka C. High tibial osteotomy for valgus and varus deformities of the knee. Int Orthop. 2001; 25(2):93-6.
63. Miniaci A, Ballmer FT, Ballmer PM, Jakob RP. Proximal

tibial osteotomy. A new fixation device. Clin Orthop Relat Res. 1989; 246:250-9.

64. Naudie DD, Amendola A, Fowler PJ. Opening wedge high tibial osteotomy for symptomatic hyperextension-varus thrust. Am J Sports Med. 2004; 32(1):60-70.
65. Rinonapoli E, Aglietti P, Mancini GB, Buzzi R. High tibial osteotomy in the treatment of arthritic varus knee. A medium term (small) review of 61 cases. Ital J Orthop Traumatol. 1988; 14(3):283-92.
66. Yasuda K, Majima T, Tsuchida T, Kaneda K. A ten- to 15-year follow-up observation of high tibial osteotomy in medial compartment osteoarthrosis. Clin Orthop Relat Res. 1992; 282:186-95.
67. Ducat A, Sariali E, Lebel B, Mertl P, Hernigou P, Flecher X, et al. Posterior tibial slope changes after opening- and closing-wedge high tibial osteotomy: a comparative prospective multicenter study. Orthop Traumatol Surg Res. 2012; 98(1):68-74.
68. Javidan P, Adamson GJ, Miller JR, Durand P Jr, Dawson PA, Pink MM, et al. The effect of medial opening wedge proximal tibial osteotomy on patellofemoral contact. Am J Sports Med. 2013; 41(1):80-6.
69. McNamara I, Birmingham TB, Fowler PJ, Giffin JR. High tibial osteotomy: evolution of research and clinical applications--a Canadian experience. Knee Surg Sports Traumatol Arthrosc. 2013; 21(1):23-31.
70. Agneskirchner JD, Hurschler C, Wrann CD, Lobenhoffer P. The effects of valgus medial opening wedge high tibial osteotomy on articular cartilage pressure of the knee: a biomechanical study. Arthroscopy. 2007; 23(8):852-61.
71. Han SB, Lee DH, Shetty GM, Chae DJ, Song JG, Nha KW. A “safe zone” in medial open-wedge high tibia osteotomy to prevent lateral cortex fracture. Knee Surg Sports Traumatol Arthrosc. 2013; 21(1):90-5.
72. Hernigou P. Open wedge tibial osteotomy: combined coronal and sagittal correction. Knee. 2002; 9(1):15-20.
73. Noyes FR, Goebel SX, West J. Opening wedge tibial osteotomy: the 3-triangle method to correct axial alignment and tibial slope. Am J Sports Med. 2005; 33(3):378-87.
74. Asada S, Akagi M, Mori S, Matsushita T, Hashimoto K, Hamanishi C. Increase in posterior tibial slope would result in correction loss in frontal plane after medial open-wedge high tibial osteotomy. Knee Surg Sports Traumatol Arthrosc. 2012; 20(3):571-8.
75. El-Azab H, Halawa A, Anetzberger H, Imhoff AB, Hinterwimmer S. The effect of closed- and open-wedge high tibial osteotomy on tibial slope: a retrospective radiological review of 120 cases. J Bone Joint Surg Br. 2008; 90(9):1193-7.
76. Nha KW, Kim HJ, Ahn HS, Lee DH. Change in Posterior Tibial Slope After Open-Wedge and Closed-Wedge High Tibial Osteotomy: A Meta-analysis. Am J Sports Med. 2016.
77. Agneskirchner JD, Hurschler C, Stukenborg-Colsman C, Imhoff AB, Lobenhoffer P. Effect of high tibial flexion osteotomy on cartilage pressure and joint kinematics: a biomechanical study in human cadaveric knees. Winner of the AGA-DonJoy Award 2004. Arch Orthop Trauma Surg. 2004; 124(9):575-84.
78. Reising K, Strohm PC, Hauschild O, Schmal H, Khattab M, Südkamp NP, et al. Computer-assisted navigation for the intraoperative assessment of lower limb alignment in high tibial osteotomy can avoid outliers compared with the conventional technique. Knee Surg Sports Traumatol Arthrosc. 2013; 21(1):181-8.
79. Iorio R, Pagnottelli M, Vadalà A, Giannetti S, Di Sette P, Papandrea P, et al. Open-wedge high tibial osteotomy: comparison between manual and computer-assisted techniques. Knee Surg Sports Traumatol Arthrosc. 2013; 21(1):113-9.
80. Schröter S, Gonser CE, Konstantinidis L, Helwig P, Albrecht D. High complication rate after biplanar open wedge high tibial osteotomy stabilized with a new spacer plate (Position HTO plate) without bone substitute. Arthroscopy. 2011; 27(5):644-52.
81. Spahn G. Complications in high tibial (medial opening wedge) osteotomy. Arch Orthop Trauma Surg. 2004; 124(10):649-53.
82. van den Bekerom MP, Patt TW, Kleinhout MY, van der Vis HM, Albers GH. Early complications after high tibial osteotomy: a comparison of two techniques. J Knee Surg. 2008; 21(1):68-74.
83. Brinkman JM, Luites JW, Wymenga AB, van Heerwaarden RJ. Early full weight bearing is safe in open-wedge high tibial osteotomy. Acta Orthop. 2010; 81(2):193-8.
84. Takeuchi R, Ishikawa H, Aratake M, Bito H, Saito I, Kumagai K, et al. Medial opening wedge high tibial osteotomy with early full weight bearing. Arthroscopy. 2009; 25(1):46-53.
85. Agneskirchner JD, Freiling D, Hurschler C, Lobenhoffer P, et al. Primary stability of four different implants for opening wedge high tibial osteotomy. Knee Surg Sports Traumatol Arthrosc. 2006; 14(3):291-300.
86. Pape D, Kohn D, van Giffen N, Hoffmann A, Seil R, Lorbach O. Differences in fixation stability between spacer plate and plate fixator following high tibial osteotomy. Knee Surg Sports Traumatol Arthrosc. 2013; 21(1):82-9.

87. Kyung HS, Lee BJ, Kim JW, Yoon SD. Biplanar Open Wedge High Tibial Osteotomy in the Medial Compartment Osteoarthritis of the Knee Joint: Comparison between the Aescula and TomoFix Plate. Clin Orthop Surg. 2015; 7(2):185-90.
88. Golovakha ML, Orljanski W, Benedetto KP, Panchenko S, Büchler P, Henle P, et al. Comparison of theoretical fixation stability of three devices employed in medial opening wedge high tibial osteotomy: a finite element analysis. BMC Musculoskelet Disord. 2014; 15:230.
89. Samani SS, Kachooei AR, Ebrahimzadeh MH, Omidi Kashani F, Mahdavian Naghashzargar R, Razi S. Application of Orthopedic Dual Sliding Compression Plate (ODSCP) in High Medial Tibial Open Wedge Osteotomies. Iran Red Crescent Med J. 2013; 15(4):335-9.
90. Staubli AE. Radiologische Heilungsvorgänge nach öffnender kniegelenknaher Tibiaosteotomie. In: Lobenhoffer P, Agneskirchner JD, Galla M, eds. Kniegelenknahe osteotomien: indikation, planung, operationstechnik mit plattenfixateuren. New York: Georg Thieme Verlag KG; 2006: p. 65-78.
91. Onodera J, Kondo E, Omizu N, Ueda D, Yagi T, Yasuda K. Beta-tricalcium phosphate shows superior absorption rate and osteoconductivity compared to hydroxyapatite in open-wedge high tibial osteotomy. Knee Surg Sports Traumatol Arthrosc. 2014; 22(11):2763-70.
92. Gaasbeek RD, Toonen HG, van Heerwaarden RJ, Buma P. Mechanism of bone incorporation of beta-TCP bone substitute in open wedge tibial osteotomy in patients. Biomaterials. 2005; 26(33):6713-9.
93. Meidinger G, Imhoff AB, Paul J, Kirchhoff C, Sauerschnig M, Hinterwimmer S. May smokers and overweight patients be treated with a medial open-wedge HTO? Risk factors for non-union. Knee Surg Sports Traumatol Arthrosc. 2011; 19(3):333-9.
94. Kuremsky MA, Schaller TM, Hall CC, Roehr BA, Masonis JL. Comparison of autograft vs allograft in opening-wedge high tibial osteotomy. J Arthroplasty. 2010; 25(6):951-7.
95. Luites JWH, BJ, van Heerwaarden R, Valstar ER, Wymenga AB. Stability of open vs closed wedge high tibial osteotomy measured with roentegen stereophotogrammetric analysis in a randomised clinical trial. ESSKA Congress; 2006.
96. Koshino T, Yoshida T, Ara Y, Saito I, Saito T. Fifteen to twenty-eight years' follow-up results of high tibial valgus osteotomy for osteoarthritic knee. Knee. 2004. 11(6):439-44.
97. Weale AE, Lee AS, MacEachern AG. MacEachern, High tibial osteotomy using a dynamic axial external fixator. Clin Orthop Relat Res. 2001; 382:154-67.
98. Hernigou P, Ma W. Open wedge tibial osteotomy with acrylic bone cement as bone substitute. Knee. 2001; 8(2):103-10.
99. Schallberger A, Jacobi M, Wahl P, Maestretti G, Jakob RP. High tibial valgus osteotomy in unicompartmental medial osteoarthritis of the knee: a retrospective follow-up study over 13-21 years. Knee Surg Sports Traumatol Arthrosc. 2011; 19(1):122-7.
100. Duivenvoorden T, Brouwer RW, Baan A, Bos PK, Reijman M, Bierma-Zeinstra SM, et al. Comparison of closing-wedge and opening-wedge high tibial osteotomy for medial compartment osteoarthritis of the knee: a randomized controlled trial with a six-year follow-up. J Bone Joint Surg Am. 2014; 96(17):1425-32.
101. Akizuki S, Shibakawa A, Takizawa T, Yamazaki I, Horiuchi H. The long-term outcome of high tibial osteotomy - A ten- to 20-year follow-up. Journal of Bone and Joint Surgery-British Volume. 2008; 90B(5):592-6.
102. Billings A, Scott DF, Camargo MP, Hofmann AA. High tibial osteotomy with a calibrated osteotomy guide, rigid internal fixation, and early motion - Long-term follow-up. Journal of Bone and Joint Surgery-American Volume. 2000; 82A(1):70-9.
103. Brouwer RW, Raaij van TM, Bierma-Zeinstra SM, Verhagen AP, Jakma TS, Verhaar JA. Osteotomy for treating knee osteoarthritis. Cochrane Database Syst Rev. 2007; 3:CD004019.
104. Esenkaya I, Elmali N. Proximal tibia medial open-wedge osteotomy using plates with wedges: early results in 58 cases. Knee Surg Sports Traumatol Arthrosc. 2006; 14(10):955-61.
105. Miller BS, Downie B, McDonough EB, Wojtys EM. Complications after medial opening wedge high tibial osteotomy. Arthroscopy. 2009; 25(6):639-46.
106. Nelissen EM, van Langelaan EJ, Nelissen RG. Stability of medial opening wedge high tibial osteotomy: a failure analysis. Int Orthop. 2010; 34(2):217-23.
107. Giuseffi SA, Replogle WH2, Shelton WR. Opening-Wedge High Tibial Osteotomy: Review of 100 Consecutive Cases. Arthroscopy. 2015; 31(11): 2128-37.
108. Martin R, Birmingham TB, Willits K, Litchfield R, Lebel ME, Giffin JR. Adverse event rates and classifications in medial opening wedge high tibial osteotomy. Am J Sports Med. 2014. 42(5):1118-26.